

Ecosystem Level Assessments of Hypoxia Impacts on the Food Web and Fisheries of Lake Erie

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INTRODUCTION

Hypoxia (dissolved oxygen (DO) < 2 mg L⁻¹) threatens fish habitats and fisheries, and makes ecosystems more susceptible to the effects of other anthropogenic and natural stressors. In Lake Erie's central basin, seasonal hypoxia resulting from anthropogenic eutrophication (Figure 1) is known to disrupt predator-prey interactions through changes in spatial distributions. For example, fish will often avoid hypoxic conditions, while zooplankton, which are often more tolerant of hypoxia, will use hypoxic areas as a spatial refuge from predation (Figure 2). Several studies have examined the sublethal impacts of hypoxia on fish consumption, behavior and spatial distributions over short time periods. However, the long-term effects of hypoxia on the fish community and the ecosystem as a whole are poorly known.

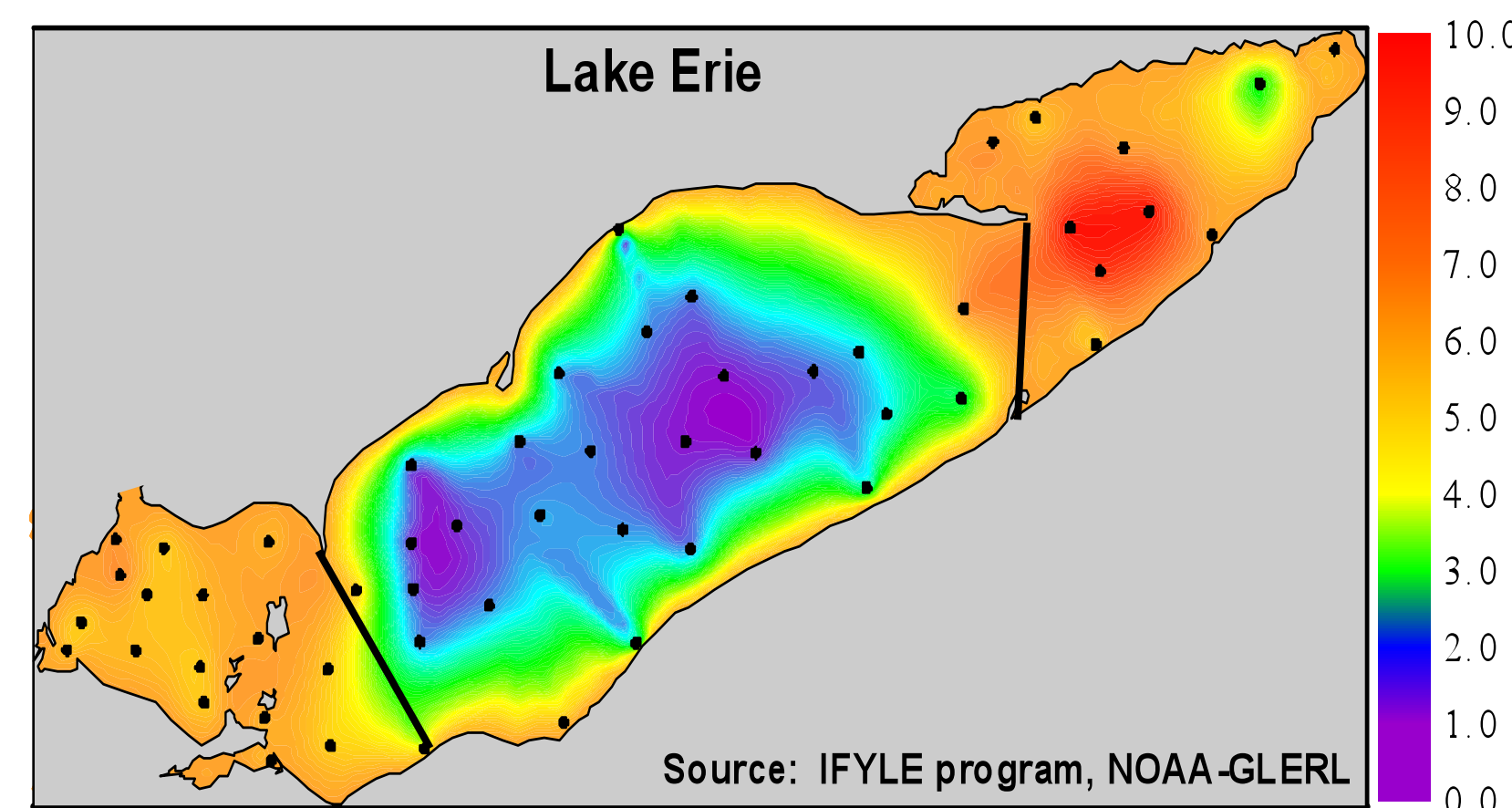


Figure 1. Large area of bottom hypoxia in the central basin (between the two black lines) of Lake Erie during September 7-11, 2005.

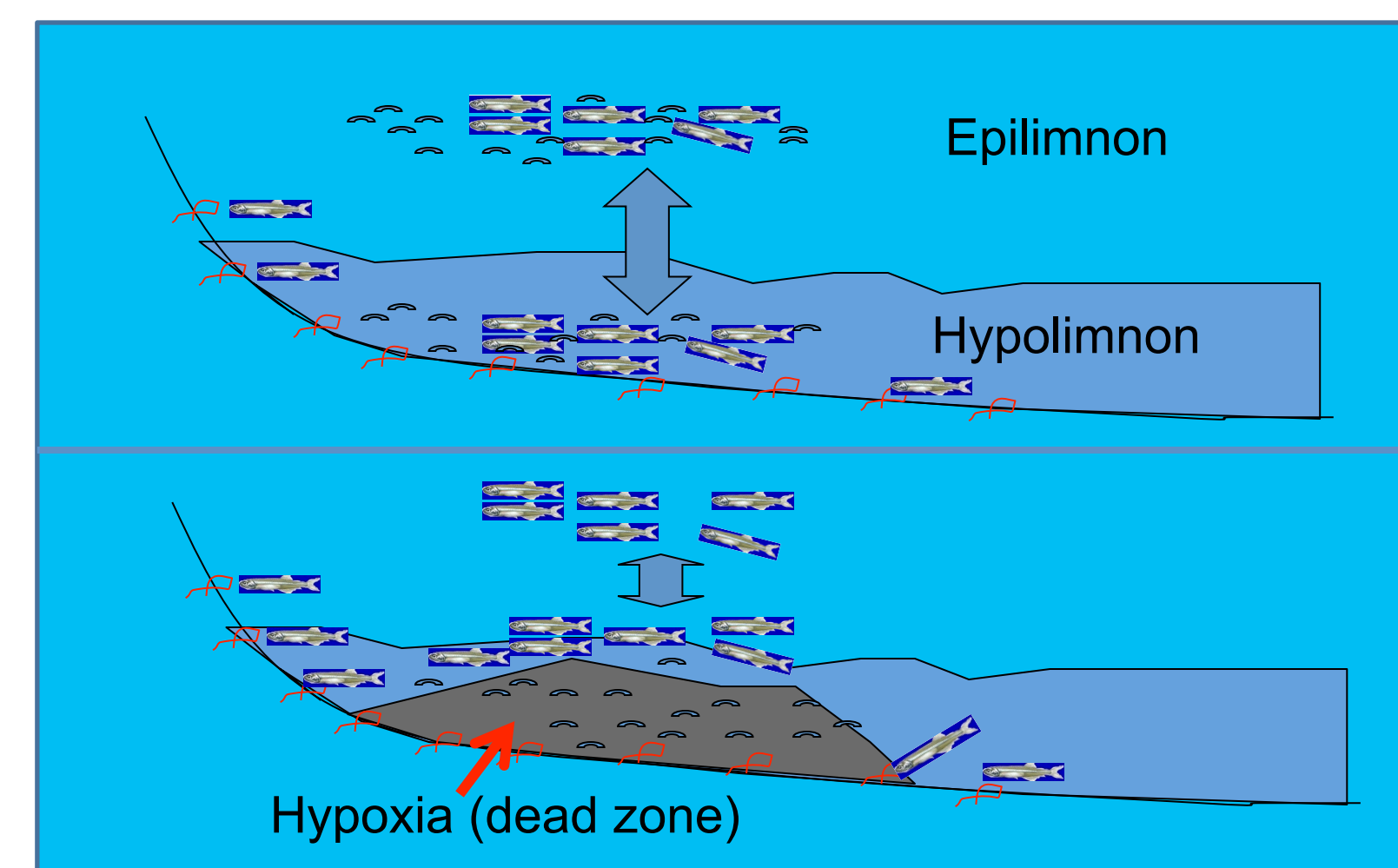


Figure 2. Comparisons of overlap between prey and predators under conditions with (upper box) and without hypoxia (lower box). Pathways of hypoxia impacts in the model include 1) decreased vulnerability of zooplankton to zooplanktivores; 2) decreased vulnerability of benthos to benthivores; and 3) decreased consumption of benthos due to low oxygen stress.

METHODS

We used an ecosystem-based model, Ecopath with Ecosim (EwE <http://www.ecopath.org/index.php>, Figure 3), to investigate the impacts of hypoxia on the Lake Erie ecosystem and fisheries in the Central Basin of Lake Erie. One of the most important features of Ecosim is its ability to simulate an ecosystem with complex trophic interactions. Ecosim uses prey vulnerability (v_{ij}) to control prey availability. (Figure 4). By linking vulnerability with hypoxic conditions, we can alter prey vulnerabilities based upon hypoxic conditions (Figure 5) and hypoxia impacts (Figure 2).

The model includes 15 fish groups, 6 benthic groups, 7 zooplankton groups, 4 algal groups, and 1 detritus group (Figure 6). Model parameters were derived from several published and unpublished databases, model simulations and state, provincial and federal monitoring data. We configured the Ecopath model using 1994 and 2005 data, and then calibrated an Ecosim model using time series data (e.g. external phosphorus loading, water temperature, dissolved oxygen, biomass of modeled groups, fishery catches) from 1994 to 2005. To simulate the system without hypoxia, we removed the forcing effects of hypoxia on prey vulnerability (Figure 5) from the simulations. By comparing the differences between ecosystems with and without hypoxia we can quantitatively assess the impacts of hypoxia on fish production.

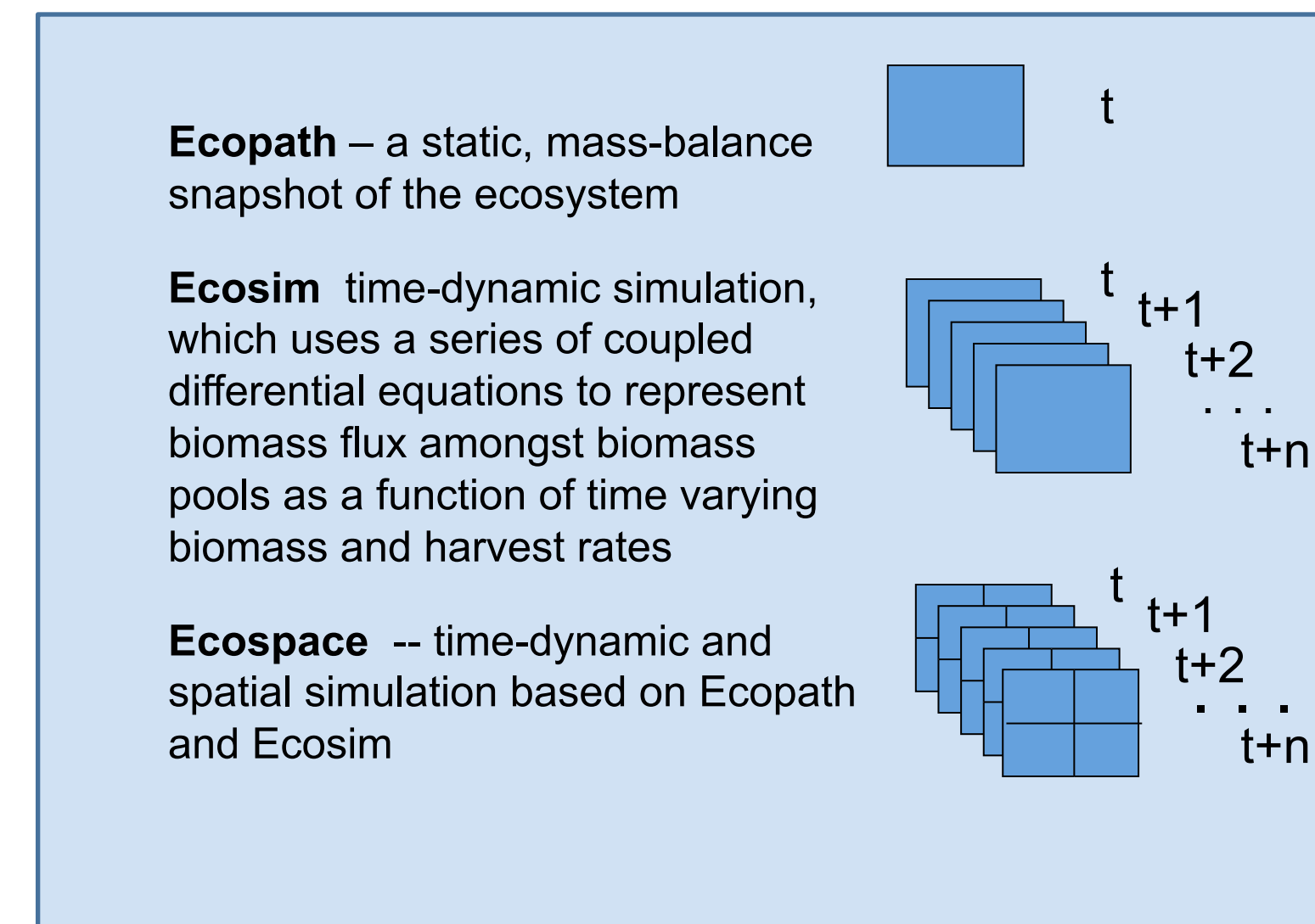


Figure 3. Ecopath with Ecosim models.

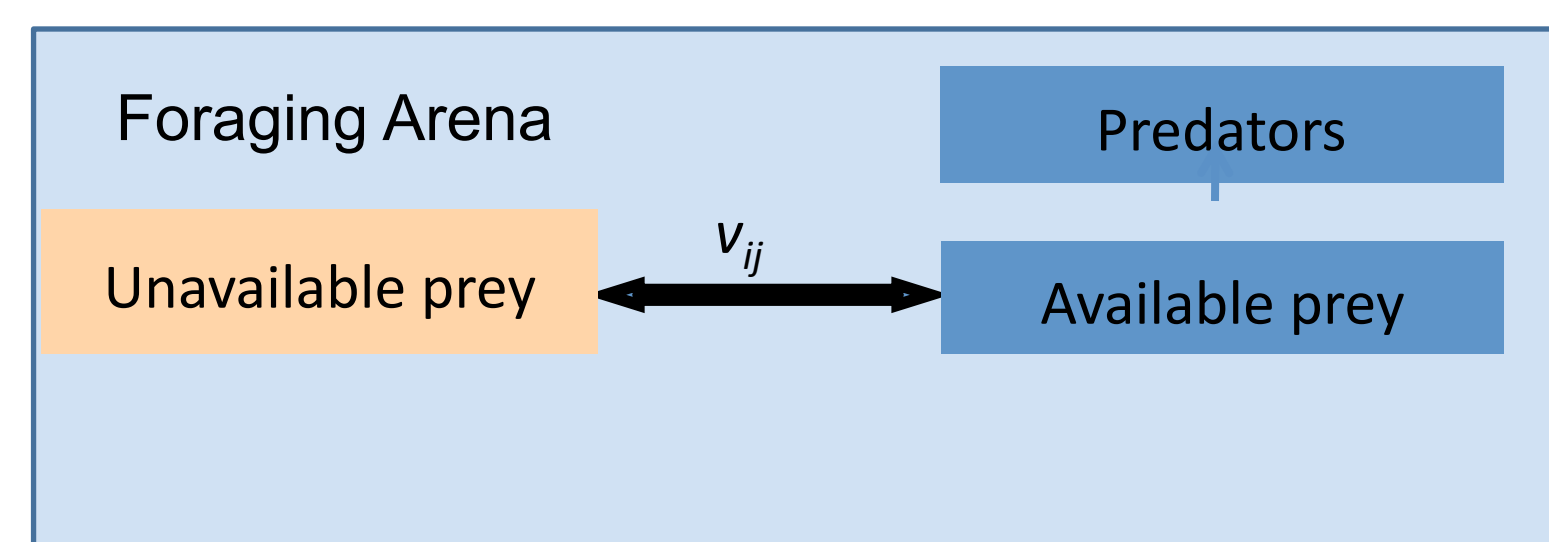


Figure 4. Foraging arena in Ecosim. If the vulnerability (v_{ij}) is high, more prey is available to predators, and top-down control is strong. If vulnerability is low, bottom-up control is strong, and less prey is available to predators.

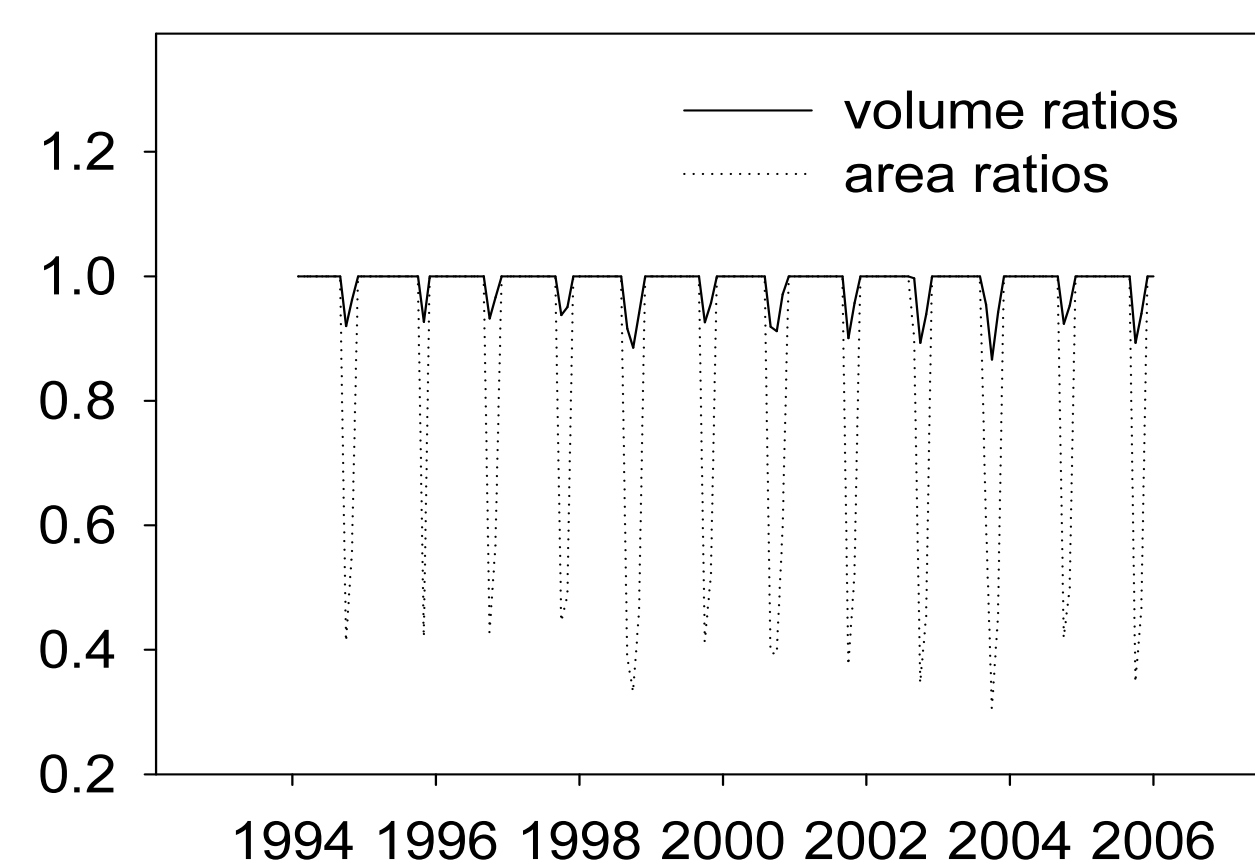


Figure 5. Volume (solid line) and bottom areal (dotted line) ratios of normoxic water to the whole central basin. The small ratio values indicate strong seasonal hypoxia. The volume ratios are used to reduce the vulnerabilities of zooplankton to planktivores. The areal ratios are used to reduce the vulnerabilities of benthos to benthivores and demersal fish, and to reduce the vulnerabilities of prey to benthos.

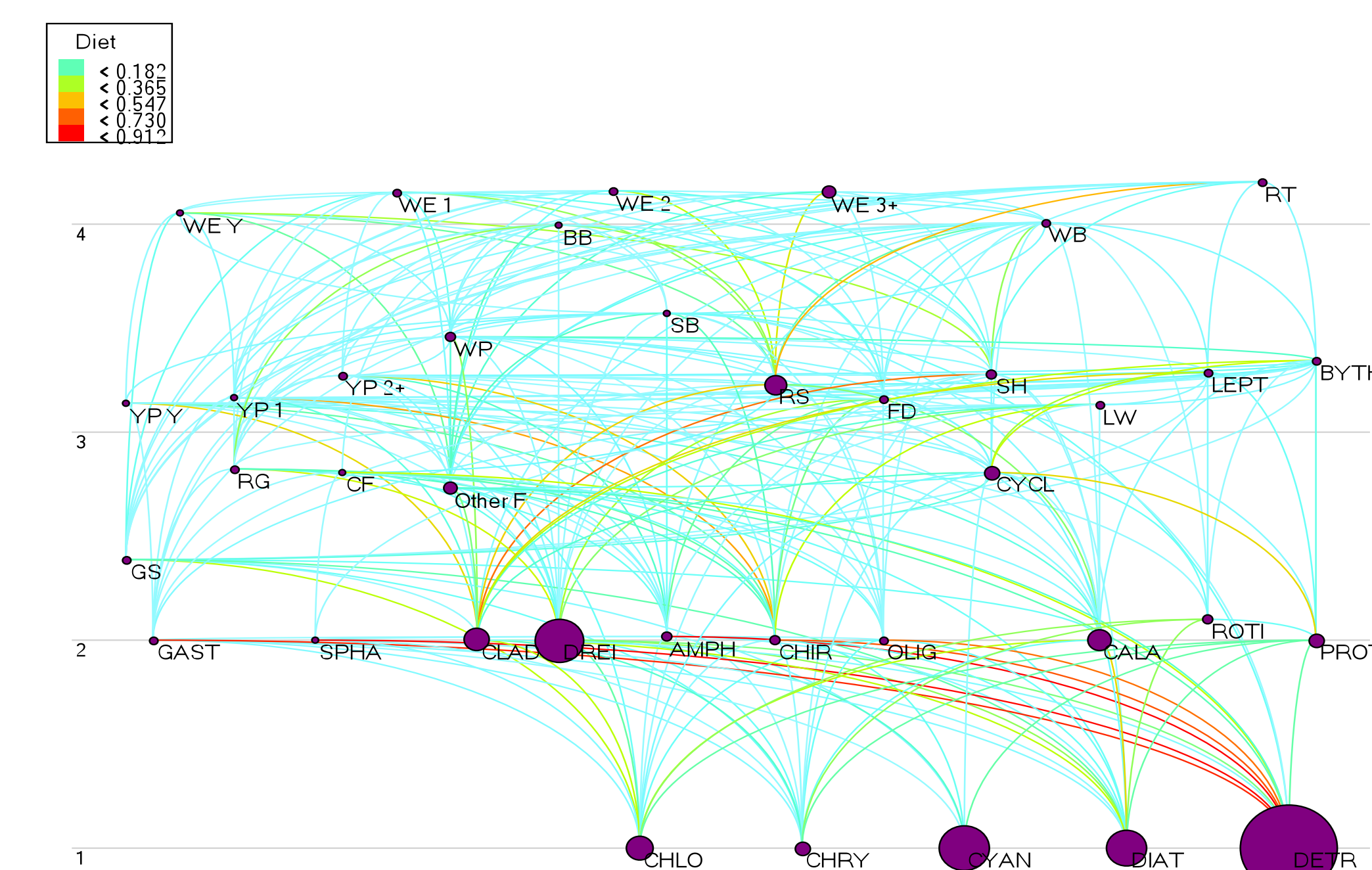


Figure 6. EwE model of Lake Erie's central basin food web. Size of purple circles is proportional to biomass. Members are: detritus, diatoms, cyanophytes, chrysophytes, chlorophytes, protists, rotifers, calanoids, oligochaetes, chironomids, amphipods, dreissenids, cladocerans, sphaerids, gastropods, cyclopoids, leptodora, bythotrephes, gizzard shad, freshwater drum, rainbow smelt, white perch, rainbow trout, white bass, smallmouth bass, burbot, lake whitefish, round goby, other forage fishes, catfish, and walleye and yellow perch age groups.

RESULTS

The balanced Ecopath model of 1994 (Figure 6) showed that detritus (DETR), diatoms (DIAT), chlorophytes (CHLO), herbivorous cladocerans (CLAD), chironomids (CHIR), and rainbow smelt (RS) were important groups in terms of biomass (purple circles) and diet components (yellowish to reddish lines in Figure 6). Model predictions matched observed data well (Figure 7). Simulations examining the effects of hypoxia on the food web are summarized in Figure 8. Benthos species biomass decreased by up to 36% while zooplankton biomass increased slightly over the simulation period (Figure 8). The biomass of nearly every fish group decreased under hypoxic conditions, with benthivores (e.g., round goby, adult yellow perch (age 2+ YP) being most affected, and planktivorous species (e.g., rainbow smelt) being least affected (Figure 8). In general, hypoxia had only a small effect on the pelagic community, as the volume of hypoxic water affected by hypoxia was small.

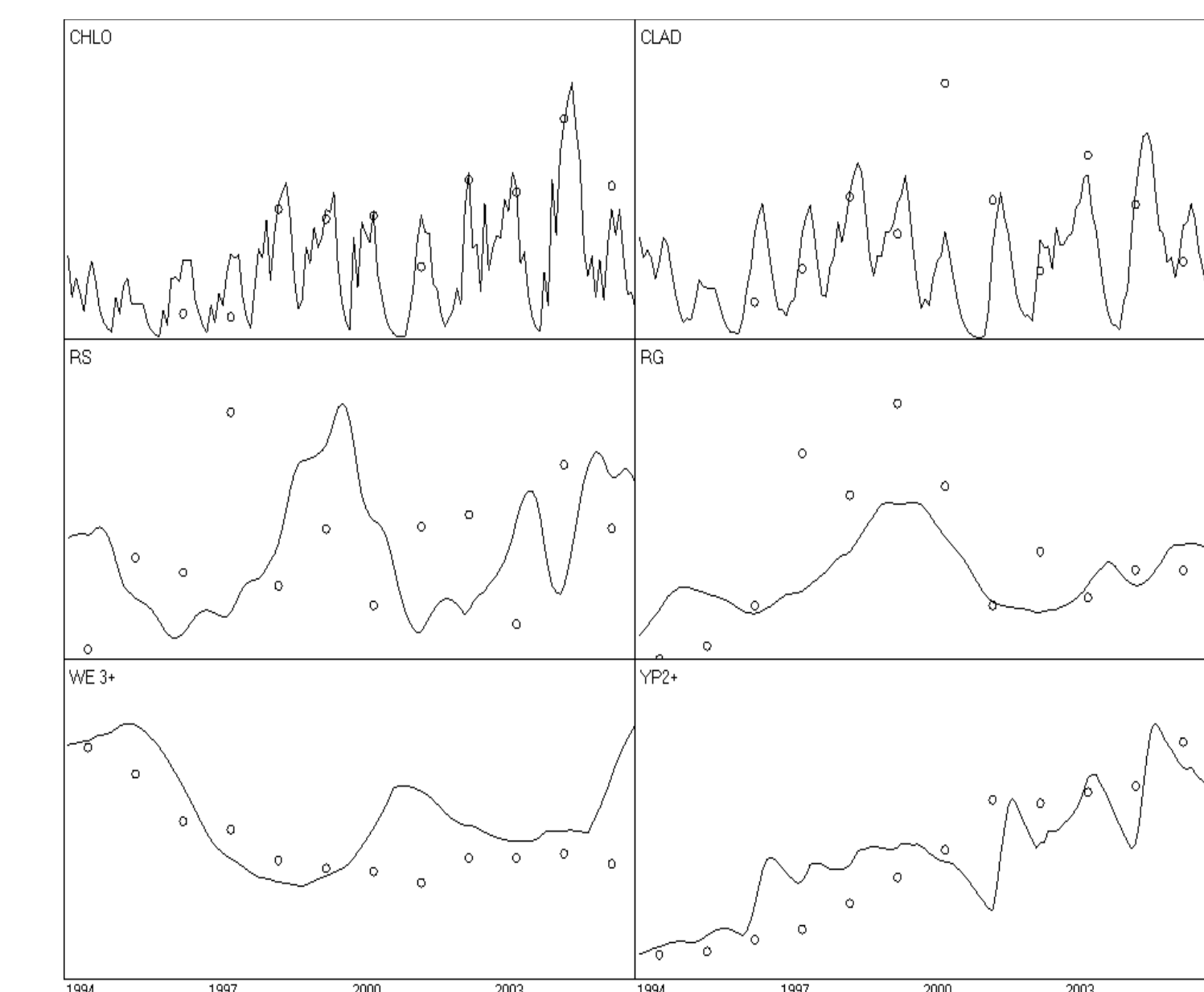


Figure 7. Comparisons of annual averaged biomass between predicted (lines) and observed (circles) data for chlorophytes (CHLO), cladocerans (CLAD), rainbow smelt (RS), round gobies (RG), adult walleye (WE 3+) and yellow perch (YP2+).

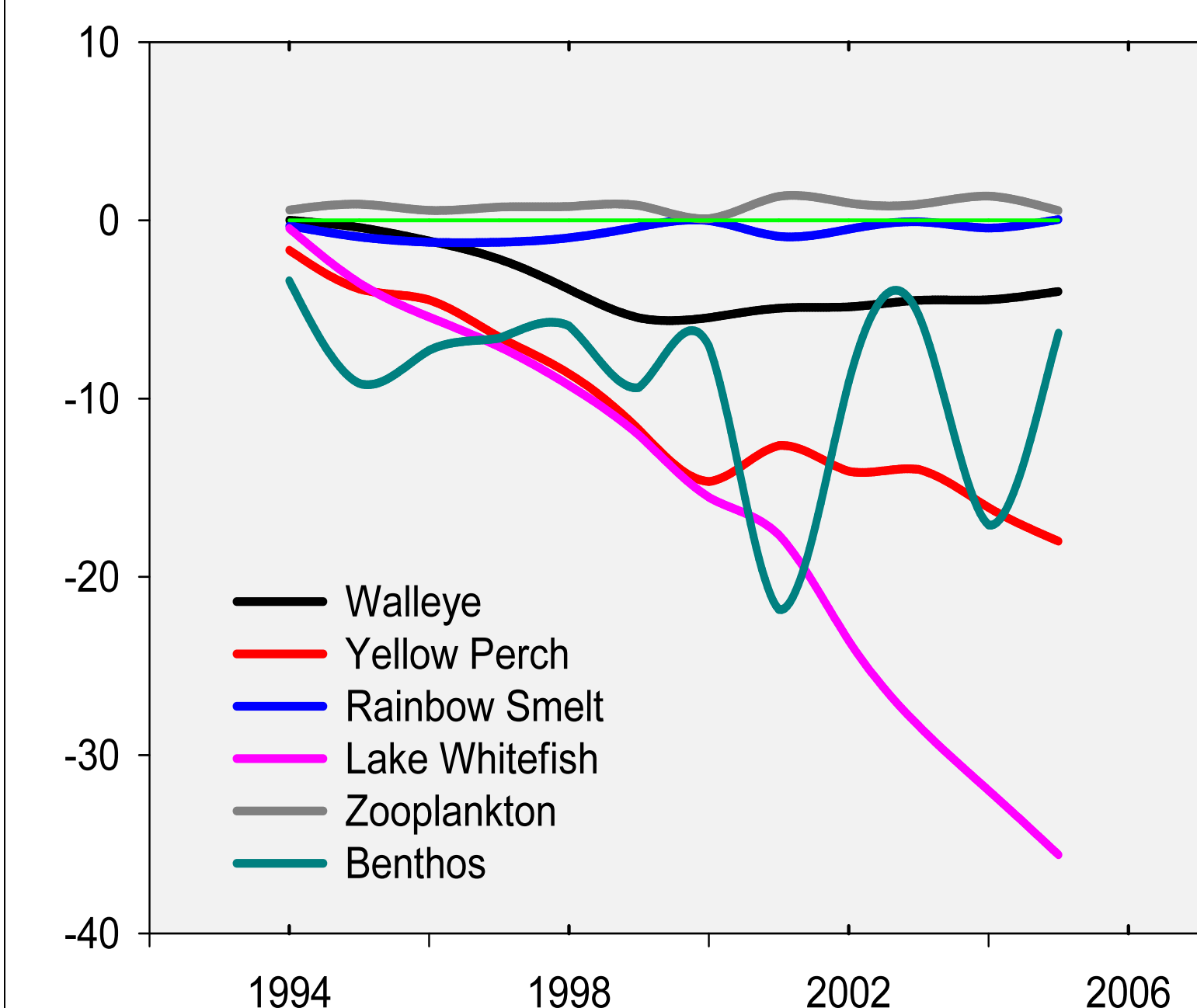


Figure 8. Differences (%) in annual averaged biomass of select trophic groups between simulations with and without hypoxia impacts on trophic interactions.

CONCLUSIONS

Although hypoxia only occurs seasonally during late summer, it has long-term, ecosystem-level impacts on benthos and benthivore groups. Hypoxia decreased the biomass of benthos and their predators through a decoupling of trophic interactions. Hypoxia also caused a decline in the biomass of walleye, the top predator fish. Hypoxia had only a small effect on zooplankton and planktivore biomass. Our continuing modeling efforts will focus on hypoxia effects on fisheries harvest, fishing catchability, and trophic interactions among fish populations.